NUMERICAL RELAYS – WHERE ARE WE NOW

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ABSTRACT

Fifteen years ago numerical relays started to replace electromechanical relays in high voltage assets in power systems. That was a revolution in protective equipment.
Fifteen years of experience in numerical relays give a good basis for analyzing them, particularly lessons learnt from experience in their commissioning, operation, maintenance and decommissioning.
Advantages and possible errors, which can be entered into a power system with implementation of numerical relays, are discussed in this paper.

1. INTRODUCTION

The application of numerical or multifunction relays started fifteen years ago when computer technology enabled their commercial use after successful development of numerical technology in protection and control equipment.
With numerical relays started a new era in protection and control of power assets. The future looked without worries, with significant space saving, quick installation, good operation and practically no maintenance.
After fifteen years of experience with numerical relays, a question can be asked: where are we now?

2. NUMERICAL RELAY CHARACTERISTICS

2.1 General Characteristics

Numerical relays are highly compact devices, characterised with fast operation, high sensitivity, self monitoring, and low maintenance.
Protection functions are the same in the nature as protection function of electromechanical relays, however, in numerical relays several protection functions are grouped in the same relay case with addition of control functions replacing several electromagnetic relays and control devices by means of only one relay.
Some control functions are combined along protection functions, such as measuring, synchronizing, fault recording, while other control functions, such as control ON, control OFF, interlocking, etc. are grouped either in a bay controller unit or along protection functions in a relay.
On Figure 1 three different options for numerical relay architecture are shown. In option a. all feeder protection and control functions are combined in the same numerical device. In option b. two numerical relays are applied, one containing main 1 protection and the other containing main 2 and backup protection together with a bay controller. In option c. main 1 protection, main 2 protection and backup protections are separated into three numerical relays, while a bay controller exists as a separate device.

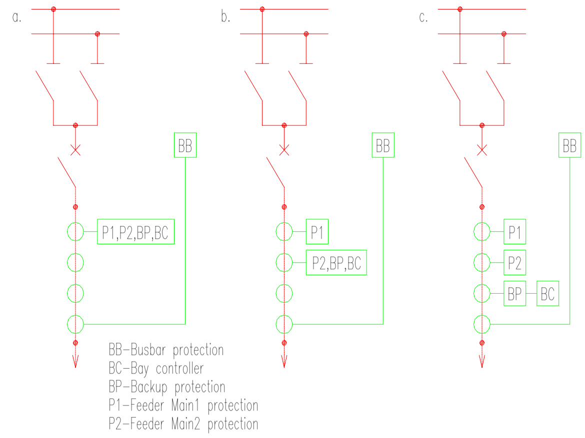

Figure 1: Application of Numerical Relays

Accommodating different functions in the same case enables significant saving in space, and in auxiliary cabling. With numerical relays there are no more requirements for spacious control and relay rooms, numerous cables in and between cubicles, which reduces the installation time.
Combining several functions enables manufacturers to produce one uniform design of a protection for different applications comparing with a wide range of electromechanical relays particularly designed for generator, transmission, distribution or industrial protection.

2.2 Grouping Different Functions

Table 1 shows a range of functional options for a numerical differential relay, which contains bay protection features (BP) and bay controller features (BC).

Table 1: Differential numerical relay

Function	BP	BC
Overall protection	X	
HV backup	x	
Mechanical trips	x	
HV CB fail	x	
HV CB pole discrepancy trip	x	
HV Trip circuit supervision	x	
HV sequential trip		x
Automatic switching		x
CB synchronising	x	
DC supply supervision	x	
CT supervision	x	
VT supervision	x	
Plant control		x
Position indication		x
Operational measurements		x

Having a relay solution with a wide range of functional options enables different applications of the same relay type in the network. For that purpose it is required to select the right functions for a particular application and disable unwanted ones.
There is a question how far to go with grouping different functions under the same case. Which option to select from Figure 1 as the right option for an application?
Without doubt all functions for a complicated extra high voltage circuit may be accommodated in the same case as shown on Figure 1a. With that option configuring and testing the relay will be very demanding and very complicated, which may lead to errors.
Also, accommodating all protection and control functions in the same device may decrease the reliability of the protection systems because of the common dc supply for all systems, shared circuitry of different systems, etc.
When designing protection system for an application in power system, it is important to consider all those factors and to make a compromise between the number of relays, protection requirements, reliability of the system, and requirements for operation and maintenance. General principles for the protection and control should be followed. The following are some recommendations for protection and control design:

- For a power transformer, high voltage and low voltage protection and control functions to be separated
- For a transmission feeder, main 1 and main 2 protection systems to be separated
- Backup protection combined with the bay controller.

2.3 Reliability of Numerical Relays

Regarding reliability manufacturers highlight the high level of reliability of numerical protection because of complete relay self-monitoring, type-tested technology.
Although additional supervision relays were used for monitoring purposes with electromechanical relays, this invariably necessitated additional external wiring, adding to the complexity of the installation. It could therefore be argued that a numerical relay, by managing and monitoring the complex circuitry, does contribute to the reliability and dependability of the protection. However, the reliability consists of reliability of all components involved in the system, such as monitoring, auxiliary supplies, etc.
Different manufacturers state different failure rates for numerical relays, from one in 75 years to one in 100 years. With one numerical relay comprising different protection systems (main 1, main 2 and backup protection), it may be impossible to provide two independent dc auxiliary supplies to each main protection system because the relay may offer only one dc supply connection. That would reduce the reliability level for both protection systems.

2.4 Remote Data Exchange

Online remote data exchange between numerical relays and remotely located devices is the real beauty of numerical technology. That offers wide options of relay settings applications or checks, data processing for network operations and maintenance purposes, or downloading fault recording data for fault analysis. This is a big advantage of numerical relays.

2.5 Service Life of Numerical Relays

A typical service life of numerical relays is between fifteen and twenty years. For comparison electromechanical relays had a service life of forty years.
Numerical relays are sophisticated devices with printed circuit boards. In case of hardware faults the relay has to be replaced, because of computer technology.
For errors in software the requirement is to download a correct or new version of relay software into the relay hardware.
When feeder protection has to be updated or modified, it is easier to replace all protection, especially if the different manufacturer is employed for protection modifications. Sometimes the numerical protection is replaced a few years after the first installation.
Rapid changes in computer technology causes a shorter service life of current numerical relays because of requirements for relay replacements when other protection and control assets are being replaced. Once when the computer technology stabilises the real service life of the numerical relays will be available.

3. SETTINGS OF NUMERICAL RELAYS

3.1 General

Numerical relays have to be set correctly to achieve good protection of the protected element of power network. Protection settings have to be calculated based on the network parameters and the characteristics of the network element to be protected. Setting calculations contain circuit parameters, numerical relay functions, protection diagram, common elements, and settings for each function.
Functions of a numerical relay can be configured in different ways. A function can be enabled or disabled. Different settings can be applied to an enabled function. All settings for various functions are stored in a software file named relay configuration file.
It is important to apply a correct relay configuration file for a particular application of the relay.

3.2 Relay Configuration File

For a particular relay application in power system it is necessary to provide a correct relay configuration file. An example of a part of the configuration file is shown on Figure 2.
The configuration file of a ‘simple’ backup current protection may consist of several A4 pages. For more complicated protection the configuration file increases.
Comparing the file from Figure 2 with settings of an electromechanical relay it is obvious that numerical relay settings are far more complicated. That complexity requires highly educated personnel in charge of relay configuration

files and also may lead to mistakes / errors.

Group	SYNC Function - Condition Setting	Value	Group	Status
6240	Switching at synchronous conditions	YES	All	<TR>
6241	Frequency threshold ASYN <--> SYN	0.04 Hz	All	<TR>
6242	Maximum voltage difference U2>U1	40.0 V	All	<TR>
6243	Maximum voltage difference U2<U1	40.0 V	All	<TR>
6244	Maximum angle difference alpha2>alpha1	20^{o}	All	<V>
6245	Maximum angle difference alpha2<alpha1	20^{o}	All	<V>
6246	Release delay at synchronous conditions	2.00 sec	All	<TR>

Group	Breaker Failure; Group BF Settings	Value	Group	Status
7004	Check Breaker contacts	OFF	A	<TR>
7005	TRIP-Timer	0.16 sec	A	<TR>

Group	Phase/Earth Overcurrent; DMT Setting	Value	Group	Status
1302	IE>> Pickup	0.10 A	A	<V>
1303	T IE>> Time Delay	oo sec	A	<TR>
1304	IE> Pickup	0.10 A	A	<V>
1305	T IE> Time Delay	oo sec	A	<TR>
1314A	IE>> active	Always	A	<TR>

Group	Phase/Earth Overcurrent; IDMT Setting	Value	Group	Status
1307	IEp Pickup	0.40 A	A	<V>
1308	T IEp Time Dial	0.54 sec	A	<V>
1310	Drop-Out Characteristic	Instantaneous	A	<TR>
1311	IEC Curve	Normal Inverse	A	<TR>

Group	Measurement Supervision Setting	Value	Group	Status
8102	Voltage Threshold for balance Monitoring	50 V	A	<TR>
8103	Balance Factor for Voltage Monitor	0.75 A	A	<TR>
8104	Current Balance Monitor	0.10 A	A	<TR>
8105	Balance Factor for Current Monitor	0.50	A	<TR>
8106	Summated Current Monitoring Threshold	0.10 A	A	<TR>
8107	Summated Current Monitoring Factor	0.10	A	<TR>

Group	Demand measurement Setting	Value	Group	Status
8301	Demand Calculation Intervals	60min per.1Sub	A	<TR>
8302	Demand Synchronization Time	On the hour	A	<TR>

Group	Min/Max measurement Setup Setting	Value	Group	Status
8311	Automatic Cyclic Reset Function	YES	A	<TR>
8312	MinMax Reset Timer	0 min	A	<TR>
8313	MinMax Reset Cycle Period	7 day(s)	A	<TR>
8314	MinMax Start Reset Cycle in	1 Days	A	<TR>

Group	Supervision; Fuse Fail Monitoring	Value	Group	Status
5302	Zero Sequence Voltage	30 V	A	<TR>
5303	Residual Current	0.10 A	A	<TR>

Figure 2: Earth fault relay - Configuration file, insert

3.3 Change Configuration of Power Network

When changing the configuration of power network or any relevant network parameter, the relay configuration file shall require modifications to be suitable for the new configuration. In that case a new relay configuration file has to be downloaded to the relay. After that the relay has to be re-commissioned.
When a feeder differential numerical relay is applied in a three-end circuit, a setting configuration file for three-end circuit has to be downloaded into the relay. If the circuit configuration is changed into two-ended one, a new setting configuration file is required for correct relay operations.
If the alternative configuration is known when protection is specified originally, it is recommended to require two relay configuration files: one original and the other for the changed network configuration in the future.
If the alternative configuration was not known when the relay has been purchased, extra costs will be required for providing new relay settings and producing a new configuration file.

3.4 Numerical Relay Maloperations

3.4.1 Maloperations Caused by Settings

Regarding the settings and configuration files the following errors of numerical relays may occur in practice:

- wrong settings downloaded into the relay
- a required function is disabled
- non-required function is enabled
- access for configuration edit/change given to unauthorised person
- access for configuration edit/change given to the manufacturer only.

3.4.2 Setting of Transformer Differential Protection

Magnetising inrush current containing second harmonic blocks the operation of differential protection. Numerical relays have facilities to set the level of the second harmonic current at which blocking occurs. When the inrush current decreases and reaches the certain value, it can cause maloperation of the differential protection. This is because at these low levels the second harmonic could reduce below the blocking setting, while the magnetising inrush current may still be above the differential setting, if set too low.

3.4.3 Setting of Distance Protection

Distance protection for special cases such as short feeders connected to high source impedance network points (generation points).
Electromechanical, and even the static relays were not able to operate below about 1 volt. Some numerical relays can be proved to perform well on the test bench for voltages much less than 1 volt. This may falsely suggest their ability to work with high source impedances, bearing in mind the harsh substation environments and pick ups on the voltage circuit.
Although manufacturers of numerical distance relays do not highlight relay operation for small voltages, the problem of protecting those special cases is still relevant for numerical distance relays.

4. COMMISSION NUMERICAL RELAYS

4.1 General

Good management is required for testing and commissioning of numerical relays to avoid mal-operations, and unnecessary tripping in the network.

4.2 Commissioning

The commissioning of numerical relays consists of Factory Tests and Site Tests.
In Factory Tests all functions are tested to prove that the relay complies with the proposed application. The protection diagram, relay configuration file, setting calculations, and the Site Test procedures have to be available prior to the Factory Tests to enable familiarisation of people involved with the tests. After the tests it is expected that a copy of the relay configuration file, downloaded into the relay, is filed with all factory test results in a folder to be sent to site together with the relay.
In Site Tests a reduced number of tests are carried out to prove that the relay performance complies with the agreed solution. For that purpose it is important that the

configuration file, which has successfully completed Factory Tests, is downloaded in the relay being tested.
A good practice recommends that Factory Tests are witnessed by the purchaser or his representative.

4.3 Changing Relay Configuration

When network conditions are changed the existing relay configuration file has to be replaced by means of a new file containing new settings. After applying the new configuration file re-commissioning of the relay has to be carried out to prove the reconfigured relay. Numerical relays offer the flexibility of catering for various power system configurations in the form of setting groups. Network condition changes can then be accommodated by selecting the appropriate setting groups. This demands strict management and procedures.

4.4 Numerical Relay Maloperations

If the commissioning of numerical relays are not carried out properly various errors may occur in numerical relays causing them to maloperate. Some examples are:

- wrong relay configuration file downloaded in the relay
- incorrect configuration of the Numerical relay, with inadequate commissioning tests.

As an example of relay maloperation is a high voltage feeder equipped with feeder protection, Delayed Auto Reclosing (DAR) and ferro-resonance quench features. The numerical relay had been configured to detect and quench ferro-resonance on a circuit, as well as perform DAR. The complexity of configuring this arrangement in a numerical relay, meant the relay permitted DAR to occur while the ferro-resonance earth switch was operated. Following this event, the relay software was revised, and given a new number. However, human error resulted in another software file to be downloaded onto the relay. This was done while the circuit was alive and resulted in important feeders tripping. Correct software, uploaded in this way, would not have resulted in the maloperation. The solution was implementation of isolation facilities, during uploading, regardless of the confidence in the software.
Yet another example is related to the configuration of current transformer star points in the relay. An existing site was being upgraded and new protection fitted. The site engineer noticed a current transformer star point setting in a unit protection, which to him appeared abnormal, modified it, and this lead to maloperation when the circuit was put on load. In the past, correcting for current transformer star points would have required complicated secondary wiring changes, and would have discouraged such endeavours.

5. DECOMMISSIONING

After the end of service life numerical relays have to be decommissioned and dismantled.
Numerical relays as very compact and small devices require a small quantity of raw material for their manufacturing, which make them environmentally friendly.
Numerical relays are also very handy for dismantling because of clip connections and rack system.
Regarding recycling and recovery after dismantling, a particular attention has to be paid to electronic circuit boards, which require specific end-of-life processing. Other parts can be recovered or recycled, such as recyclable thermoplastics, copper, etc.
Some manufacturers produce brochures, where instructions describe how to separate and sort numerical relay components after dismantling.
When purchasing numerical relays, requirements for relays decommissioning and disposal/recycling/recovery should be included either in the specification or in tendering process.

5. CONCLUSION

Numerical relays are highly compact devices, characterised with fast operation, high sensitivity, self monitoring, and low maintenance.
Online remote data exchange between numerical relays and remotely located devices offers remote relay settings applications, data processing for network operations and maintenance, or remotely analysing recorded fault data.
With numerical protection, because of the numerous and complex settings to be entered, it is important to have procedures, processes and standards in place, to ensure careful management of the modern numerical relays. It has been found possible to standardise on a large number of the settings entered, leaving a few site specific settings to be determined. It is important that the settings are not entered manually on site, but downloaded into the relay, after careful checking, and factory tests.
Numerical relays are environmentally friendly because of very small amount of raw material used for their manufacturing, easy dismantling and the good component rate of recovery and recycling.
Only printed circuit boards have to be separated and processed separately.

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